EXPERIMENTAL CONSEQUENCES OF THE HYPOTHESIS ABOUT A FUNDAMENTAL MASS IN HIGH - ENERGY PHYSICS

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Abstract

This work continues earlier investigations towards constructing a consistent new Quantum Field Theory with fundamental mass M, defining a hypothetical but universal scale in the region of ultrahigh energies. From a theoretical point of view the fundamental mass M and corresponding to it the fundamental length $\ell = \hbar/Mc$ are supposed to play a major role such as Planck's constant $\hbar$, the speed of light c or Newton's gravitational constant κ.

The standard Quantum Field Theory is recovered in the flat limit. Furthermore, on the basis of this theory various cross sections of fundamental processes have been calculated. Some results revealed that the novel interaction induced via the geometric structure of the momentum space do not keep spirally. As a characteristic feature this interaction inherently leads to a violations of fundamental symmetries, such as P and CP. Also the helicity will no longer be preserved at ultra-high energies.

Key words: Fundamental mass, fundamental length, equation with universal scales

1. Introduction

In the present work some experimental predictions of the Quantum Field Theory (QFT) with fundamental mass (FM) M (respectively for the fundamental length $\ell = \hbar/Mc$) will be revealed. This fundamental mass M and corresponding to it the fundamental length $\ell = \hbar/Mc$ may play a similar role as Planck's constant $\hbar$, the speed of light c or Newtonian

gravitational constant κ, defining a characteristic scale in the region of ultrahigh energies.

The existence of so-called ultra-violet divergences, i.e., infinitely large values, arising as a result of direct application of equations QFT in area of very small space-time distances, or equivalently, to the region of very high energies and pulses is one of lacks of standard QFT. There were ideas about presence of a new universal constant dimension of mass or length in nature[1], which would fix the certain scale in the field of high energies or on small space-time distances because of the purpose to give the decision of this problem in the most various contexts. They testify only that the modern high-energy physics still far will defend from that boundary behind which can will be shown new geometrical properties of space - time.

From a position of today it is represented to many theorists rather probable, that the "true" theory of the field, capable to give the adequate description of all interactions of elementary particles, will be at least renormalized Lagrange theory having local gauge supersymmetry. It is asked, whether such scheme can contain parameter such as fundamental length? The future experiments can give the answer to this question only. However numerous attempts to construct more general QFT, proceeding from such parcels, did not give essential results. This failure is probable speaks that for today the mathematical theory of spaces which geometry only "in small" differs from (pseudo)Euclidean geometry is not developed almost and, especially, in similar kinds of spaces the mathematical device adequate to requirements QFT is not advanced. But, the output from the created situation is prompted by QFT. As it is known, within the framework of this theory space-time description is completely equal in rights with the description in terms pulse-power variables. If the theory is formulated in pulse representation fields, sources, Green's functions and other attributes of the theory appear certain in four-dimensional (pseudo) Euclidean p-space. This modified quantum field theory has an elegant geometrical basis: in momentum representation one faces a momentum space corresponding to a de Sitter space of curvature radius [2, 3, 4, 5, 6, 7, 10, 13, 14, 15, 16, 17, 18]. The approach developed earlier has been based on the assumption that the momentum space possesses the geometric structure of a de Sitter space of constant curvature. A key role has been be assigned to this constant radius of curvature.

We shall investigate the phenomenological (experimental) consequences of such a quan-

tum field theoretical model. Calculations of cross sections corresponding to various basic processes will be carried out up to the second order. On the basis of the QFT with FM [3, 4, 5, 6, 7, 10, 13, 16, 17], calculations of cross sections for processes such as $e^-e^- \to e^-e^-$, $e^-e^+ \to e^-e^+$ and $e^-e^+ \to \mu^-\mu^+$ have been carried out by taking into account the polarization of particles. The contribution of the FM could be revealed. Some experimental consequences [4, 5, 13, 16, 17] are predicted. In all these calculations the polarization of particles will be taken into account.

Experimental detection of the new fundamental scale testifying to existence specific atoms of space - time, would mean, that in knowledge of a nature the new step, commensurable on the value with opening quantum properties of a matter is made. According to modern data, if the constant ℓ also exists then if submits to restriction[1] $\ell \leq 10^{-19}$ cm. This boundary still extremely far will defend from " Planck lengths " $\ell_{Planck} \sim 10^{-33}$ cm, determining spatial scales of effects of quantum gravitation. And, certainly, it is impossible to exclude, that in process of overcoming an enormous interval $10^{-19} - 10^{-33}$ cm will be open the new physical phenomena and laws, associate with new " scale of a nature " - fundamental length ℓ .

2. "Fundamental" equation with universal scales

In the papers cited [2, 3, 6, 7], the key role was played by the following geometric idea: to construct QFT providing an adequate description of particle interactions at super high energies, one should write down the standard field theory in the momentum representation, and then pass it from the Minkowski p-space to the de Sitter p-space with a large enough radius.

The de Sitter space has a constant curvature. Depending on its sign there are two possibilities

$$p_0^2 - p_1^2 - p_2^2 - p_3^2 + p_5^2 \equiv g^{KL}P_K P_L = M^2;$$
$$K, L = 0, 1, 2, 3, 5 \tag{1}$$
$$(positive \; curvature: \quad g^{00} = -g^{11} = -g^{22} = -g^{33} = g^{55} = 1)$$

[1]For the investigation of the inner structure of hybrid stars in Ref. [19] it is also introduced the fifth dimension. Because of the extra motion in the fifth dimension, an extra mass term appears in $4D$ description. The length of $\sim 10^{-12} - 10^{-13} cm$, implied He extra "mass" $m \sim 100 Mev$

$$p_0^2 - p_1^2 - p_2^2 - p_3^2 - p_5^2 \equiv g^{KL}P_K P_L = -M^2;$$
$$K, L = 0, 1, 2, 3, 5 \tag{2}$$
$$(negative\ curvature: \quad g^{00} = -g^{11} = -g^{22} = -g^{33} = -g^{55} = 1).$$

Unlike the previous papers of this sequel, the new theory is being constructed from the beginning in the configuration representation [10].

The non-Euclidean Lobachevsky imaginary 4-space (2) is also called the Lobachevsky imaginary 4-space [11]. It is natural that QFT based on momentum representation of the form (1)-(2) must predict new physical phenomena at energies $E \geq$ M. In principle, the parameter may turn out to be close to the Planck mass $M_{Planck} = \sqrt{\frac{\hbar c}{\kappa}} \approx 10^{19}$ GeV. Then, the new scheme should include quantum gravity. The standard QFT corresponds to the "small" 4-momentum approximation

$$|p_0|, |\vec{p}| \ll M \quad p^5 = g^{55}p_5 \cong M,$$

which formally can be performed by letting $M \to \infty$ ("flat limit"). Such features of the considered generalization of the theory as geometricity and minimality are intriguing. This is due to the fact that the Minkowski momentum 4-space having a constant zero curvature is a degenerate limiting form of each of the spaces with constant nonzero curvature (1)-(2). The formulation of QFT with fundamental mass discussed in this paper is based on the quantum version of the de Sitter equation (2) i.e. on the five-dimensional field equation

$$\left[\frac{\partial^2}{\partial x^\mu \partial x_\mu} - \frac{\partial^2}{\partial x_5^2} - \frac{M^2 c^2}{\hbar^2} \right] \Phi(x, x^5) = 0, \qquad \mu = 0, 1, 2, 3. \tag{3}$$

derived from (2, using the following substitution, standard for quantum theory:

$$p_\mu = i\hbar \frac{\partial}{\partial x^\mu}$$

and

$$p_5 = i\hbar \frac{\partial}{\partial x^5}.$$

We deliberately use in (3)the normal units to emphasize those three universal constants $\hbar$, c and M are grouped into one parameter - fundamental length $\ell = \hbar/Mc$. Eq. (3) may be considered as the "fundamental" equation of motion. It is natural to extend the term "fundamental" to Eq. (3) itself (for short f.e.). All the fields independent of their

tensor (or spinor) character must obey Eq. (3) since similar universality is inherent in the "classical" prototype, i.e. - De Sitter p-space (2). As applied to scalar, spinor, vector and other fields we shall write down the five-dimensional wave function $\Phi(x, x^5)$ in the form $\varphi(x, x^5)$, $\psi_\alpha(x, x^5)$ and $A_\mu = (x, x^5)$. The field theory based on f.e. (3) turns out to be more consistent and more general than the scheme developed in the de Sitter p-space (2). Thus, by virtue of (2) the 4-momentum components should obey the constraint

$$p^2 = p_0^2 - \vec{p}^{\;2} \geq -M^2,$$

which does not follow from Eq. (3). We should like to note that having placed the Cauchy problem E.q. (3) for with respect to the coordinate x^5 and just in the correct formulation in the basis of QFT, in fact, we have introduced a new concept of the field, which is not equivalent to the notion of the field developed in the theory with constant curvature momentum space. Consequently, there is a one-to-one correspondence

$$\Phi(x, x^5) \leftrightarrow \left(\begin{array}{c} \Phi(x, 0) \\ \partial\Phi(x, 0)/\partial x^5. \end{array} \right)$$

In other words, the statement that to each field in the 5-space there corresponds its wave function $\Phi(x, x^5)$, obeying E.q. (3), implies that each of these fields in the usual space-time is described by the wave function with a doubled number of components

$$\left(\begin{array}{c} \Phi(x, 0) \\ \partial\Phi(x, 0)/\partial x^5 \end{array} \right) = \left(\begin{array}{c} \Phi_1(x) \\ \Phi_2(x) \end{array} \right).$$

From here we see that fields are doubled. It appears the field $\Phi_2(x)$ participates only in interactions. Due to it there are new members in diagrams. Then, it is natural to assume that the initial data obey the Lagrangian equations of motion following from the action principle

$$S = \int d^4x L \left[\Phi(x, 0), \frac{\partial\Phi(x, 0)}{\partial x^5} \right].$$

The basic problem of the new theory was is to construct explicit expressions for the Lagrangians

$$L \left[\Phi(x, 0), \frac{\partial\Phi(x, 0)}{\partial x^5} \right]$$

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in physically interesting cases, to clarify the meaning of additional field variables and to extract new physical effects in the region of super-high energies $E \geq M$. Partially, this problem has been solved earlier [2, 6, 7]. Thus, a doubled number of field degrees of freedom specific of the new scheme disappears as M→ ∞ . Hence, specifically,

$$\lim_{M \to \infty} L \left[\Phi(x, 0), \frac{\partial \Phi(x, 0)}{\partial x^5} \right] = L \left[\Phi(x, 0) \right].$$

Certainly, if in formulating the Cauchy problem we imposed the initial conditions at an arbitrary fixed value $x^5 = const$, then all our conclusions would be the previous ones and the formulae would undergo trivial changes. For instance, there would appear the following expression for the action

$$S = \int_{x^5 = const} d^4 x L \left[\Phi(x, x^5), \frac{\partial \Phi(x, x^5)}{\partial x^5} \right].$$

Thus, in Ref. [10] we receive actions for scalar, Dirac and vector fields. Basically symmetry of the equation of motion - simultaneously symmetry of action. Therefore it is satisfied

$$\partial S / \partial x^5 = 0.$$

3. Results and Conclusion

Could the advanced theory be free from ultra-violet divergences? At the present we do not have the final answer what this issue is concerned, however, we can calculate effective cross sections of some processes which are in good agreement with experiments, and this allows to estimate the contribution of fundamental mass. We investigate various aspects QFT with FM. It is shown that the contribution of the auxiliary fields to the Lagrangians of the QFT with FM is such that the sum of the kinetic terms corresponding to scalar and Majorana fields is invariant under suppersymmetry transformations inherent in the Wess-Zumino model [8, 9]. It is offered on basis QFT with FM the Rotation Invariant Gauge Model with the compact momentum space [12, 18]. Concept of Stochastic Quantization of the Abelian Fields and Fundamental Mass [15]. But, the main attention is given to application of our theory to various electrodynamic processes [4, 5, 13, 16, 17]. In the field theory standard procedure of calculation of any value representing interest from the physical point of view, is based on Feynman rules. The effective application of these rules substantially simplifies calculations. The most important in Feynman rules are expressions

for propagator and tops describing structure of the theory. We especially would like to emphasize that any reorganization of the base of field theory first of all is a call to quantum electrodynamics (QED) single its predictions excellently be can coordinated to a number of high precisions experiments. Therefore the hypothesis about FM at the beginning should be considered with reference to QED. The requirement of gauge invariance of QED with FM results in appearing of new interactions which intensity is defined by the parameter of FM. Characteristic feature of these interactions is obvious P and CP-symmetry violation, and also not preservation of helicity at high-energy. Our calculations show, that the basic test revealing distinction between standard and new QED processes with the polarized particles. Therefore we shall consider processes in view of particles polarization. We have shown some experimental consequences of the hypothesis about FM at high-energy [4, 5, 16, 17]. In comparison with usual QED new Lagrangian contains additional members, which in diagram technique should be with compared new vertices

$$e(q + p)_\mu \gamma^5 \quad and \quad \frac{-\alpha}{\pi} \gamma^5 \sigma_{\mu\nu}.$$

On basis of new Lagrangian QED, containing FM M, we investigate the section and asymmetry of $e^- e^- \to e^- e^-$, $e^- e^+ \to e^- e^+$, $e^- e^+ \to \mu^- \mu^+$ processes, in view of particles polarization. It is received differential sections

$$\left[\frac{d\sigma}{d\Omega} \right]^{e^- e^- \to e^- e^-}_{\lambda_1 \lambda_2 \to \lambda_1' \lambda_2'} \quad , \quad \left[\frac{d\sigma}{d\Omega} \right]^{e^- e^+ \to e^- e^+}_{\lambda_1 \lambda_2 \to \lambda_1' \lambda_2'} and \left[\frac{d\sigma}{d\Omega} \right]^{e^- e^+ \to \mu^- \mu^+}_{\lambda_1 \lambda_2 \to \lambda_1' \lambda_2'}$$

which contain differential sections calculated on the basis of standard QED and new members dependent on FM, where λ_1 and λ_2 are initial polarizations, λ_1' and λ_2' - final polarizations. For instance, the asymmetry combination for the process $e^- e^+ \to e^- e^+$:

$$A = \frac{(sin^8 \frac{\theta}{2} + cos^8 \frac{\theta}{2})(\frac{d\sigma}{d\Omega})_{\lambda_1 = \lambda_2} - (\frac{d\sigma}{d\Omega})_{\lambda_1 = -\lambda_2}}{(sin^8 \frac{\theta}{2} + cos^8 \frac{\theta}{2})(\frac{d\sigma}{d\Omega})_{\lambda_1 = \lambda_2} + (\frac{d\sigma}{d\Omega})_{\lambda_1 = -\lambda_2}} \qquad (4)$$

in the usual QED is different from zero due to the radiation corrections but decreases at large

$$E^2 \approx \frac{\alpha m^2}{E^4} ln \frac{E^2}{m^2}.$$

At the energies of the large electron-positron storage ring accelerator at CERN, the radiation corrections will be negligibly small. Then the main contribution to the quantity A

will come from the new interaction provided the FM varies from $M = 1000 GeV$. If helicities of beginning particles are identical $\lambda_1 = \lambda_2$, process of annihilation $e^- e^+ \rightarrow \mu^- \mu^+$ in usual QED follows the account of radiating corrections and cross section decreases with energy of colliding particles. However in our case we have

$$\left(\sigma_{tot} \right)^{e^+ e^- \rightarrow \mu^+ \mu^-} = \frac{\pi}{3} \frac{\sigma}{M^2}.$$

On the basis of new QFT containing of FM cross sections and asymmetry of processes $e^- e^- \rightarrow e^- e^-$, $e^- e^+ \rightarrow e^- e^+$ and $e^- e^+ \rightarrow \mu^- \mu^+$ are investigated in view of polarization of particles. Investigation of differential cross sections and also asymmetry shows that in the new circuit there are the effects caused by existence of FM. New interaction does not keep spirality. In the theory P and CP-symmetry violation caused by existence of electric dipole moments (EDM) of charged particles in particular: $d = e\ell/2$. Therefore experimental detection of EDM at electron, μ-mesons and τ- lepton would have extremely important value for the developed approach.

For more detailed research QFT with FM and revealings of contribution FM at the first level it is necessary to investigate cross sections of processes of Compton's scattering $\gamma + e^- = \gamma' + e^{-\prime}$, annihilation process in photon $e^- + e+ = \gamma + \gamma$ and deep-inelastic dispersion electron of on a nucleon. If to take into account the on accelerators of the future generation, to receive the polarized particles in these processes, we shall take into account polarization of particles.

As we have noted, any reorganization of the base of field theory first of all is a call to the predictions of QED. Therefore in the next stage of the investigation we shall apply to the hypothesis about FM mass with reference to QED. To investigate consequences of application of a hypothesis about FM in the following processes: Compton's scattering $\gamma + e^- = \gamma' + e^{-\prime}$, annihilation process of electron -positron pair in photon $e^- + e^+ = \gamma + \gamma$ and deep-inelastic dispersion of electrons on a nucleon. These processes will be investigated taking into account the polarizing effects in the second order of the perturbation theory. For calculations we shall use usual engineering of calculation for these processes. But thus we shall take into account also new electrodynamics vertices in rules and Feynman diagrams. Therefore in matrix elements of these processes new members of the diagram will appear. In the received sections we shall allocate a part dependent on FM. Results

of our calculations will be compare with the calculations at values $M \to \infty$ according to standard QED. Thus will come to light a new effects dependent on FM. If in a nature there will be this parameter - FM, then a prediction of the given theory in the future by experimenters will be proved or justified.

Acknowledgments

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